AD835950

Technical Memorandum No. 141

SACLANT ASW
RESEARCH CENTRE

HIGH SENSITIVITY EQUIPMENT FOR MEASURING THE HORIZONTAL ELECTRIC FIELD–STRENGTH COMPONENT IN THE FREQUENCY INTERVAL OF 1–32 Hz ON THE SEA BOTTOM IN SHALLOW WATER

by

T. STRARUP and G. TACCONI

15 MAY 1968

NATO
VIALE SAN BARTOLOMEO 400
I-19026 LA SPEZIA ITALY

AD835950

Requests for permission to reproduce the contents of this document, either wholly or in part, except in official NATO publications, should be addressed to the Director, SACLANTCEN. Normal NATO security regulations apply if this document is classified.

This document is released to a NATO Government at the direction of the SACLANTCEN subject to the following conditions:

1. The recipient NATO Government agrees to use its best endeavours to ensure that the information herein disclosed, whether or not it bears a security classification, is not dealt with in any manner (a) contrary to the intent of the provisions of the Charter of the Centre, or (b) prejudicial to the r[illegible] of the owner thereof to obtain patent, copyright, or other like statutory protection therefor.

2. If the technical information was originally released to the Centre by a NATO Government subject to restrictions clearly marked on this document the recipient NATO Government agrees to use its best endeavours to abide by the terms of the restrictions so imposed by the releasing Government.

NATO UNCLASSIFIED

TECHNICAL MEMORANDUM NO. 141

SACLANT ASW RESEARCH CENTRE
Viale San Bartolomeo 400
I 19026 - La Spezia, Italy

HIGH SENSITIVITY EQUIPMENT FOR MEASURING THE HORIZONTAL ELECTRIC FIELD-STRENGTH COMPONENT IN THE FREQUENCY INTERVAL OF 1-32 Hz ON THE SEA BOTTOM IN SHALLOW WATER

By

T. Strarup and G. Tacconi

15 May 1968

The opinions expressed herein are those of the author and are not necessarily the official views of the SACLANT ASW Research Centre. If cited in the scientific literature this document should be described as an unpublished memorandum.

TABLE OF CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	2
1. DESCRIPTION OF EQUIPMENT	3
1.1 Specification	3
1.2 Electrode Construction	3
1.3 The Dipole Frame	7
1.4 Transformer	8
1.5 Cable	10
1.6 Amplifier	10
1.7 Direction Indicator	14
2. EXPERIMENTAL RESULTS	19
CONCLUSION	25
REFERENCES	26

FIGURES

1.	Construction of Dipole	4
2.	Construction of the 7-m Long Dipole Frame	6
3.	Complete Dipole Assembly	6
4.	Amplifier Circuit	11
5.	Circuits of Unit Blocks Shown in Fig. 4	12
6.	Amplitude Characteristics of Amplifier when dc and 50 Hz Feedback are at their Extremes	13
7.	Schematic Diagram of Direction Indicator	15
8.	Direction Indicator	15
9.	Positions of Dipoles in the Gulf of La Spezia	20
10.	General Block Diagram	21
11.	Typical Recording of the Background Signal Received by Two Dipoles 1 km Apart and of the Difference Signal	22
12.	Power Spectra of Natural Background Noise Measured by Two Dipoles 1 km Apart and of the Difference Signal	23

HIGH SENSITIVITY EQUIPMENT FOR MEASURING THE HORIZONTAL ELECTRIC FIELD-STRENGTH COMPONENT IN THE FREQUENCY INTERVAL OF 1-32 Hz ON THE SEA BOTTOM IN SHALLOW WATER

By

T. Strarup and G. Tacconi

ABSTRACT

A description of a bottom-mounted electric dipole with associated orientation indicator and electronics is presented. Recordings made with the equipment are shown.

INTRODUCTION

On completion of the basic study of the measurement of the horizontal ELF electric field strength at sea using the equipment described in Ref. 1, interest shifted to the characteristics of the background noise as observed at the bottom of shallow water areas. Such an investigation — for example the measurement of correlation in space of the observed ELF electric signals — requires a very sensitive sensor and a means to orient it accurately. SACLANTCEN, following experience with floating systems, selected a high-sensitivity electric dipole system for the bottom-mounted array. A brief description of the dipole and associated electronics is given, together with an example of background noise recorded at 25 m depth near the island of Tino in the Gulf of La Spezia.

1. DESCRIPTION OF EQUIPMENT

1.1 Specification

Ideally, the dipole system should measure the potential present in an undisturbed sea and have negligible self-noise. In practice, of course, this ideal can only be approximated. In Ref. 1 the general problems of dipole design were discussed in some detail. It was pointed out that the self-noise, excluding motion, of a dipole is approximately proportional to the inverse square root of the electrode's dimensions but directly proportional to their separation. Thus it is more advantageous to have a large separation than to make large electrodes. It is also desirable to produce a system that can be constructed easily, is not difficult to lay or to recover, and is cheap. For these reasons a modular design was chosen, in which the individual modules are easy to handle and the separation can be varied by the insertion of extra sections.

1.2 Electrode Construction

Reference 1 describes an electrode made by spirally rolling sheet zinc. Due to the baffling required to reduce flow noise, its effective area was limited to that of the end of the spiral. It is

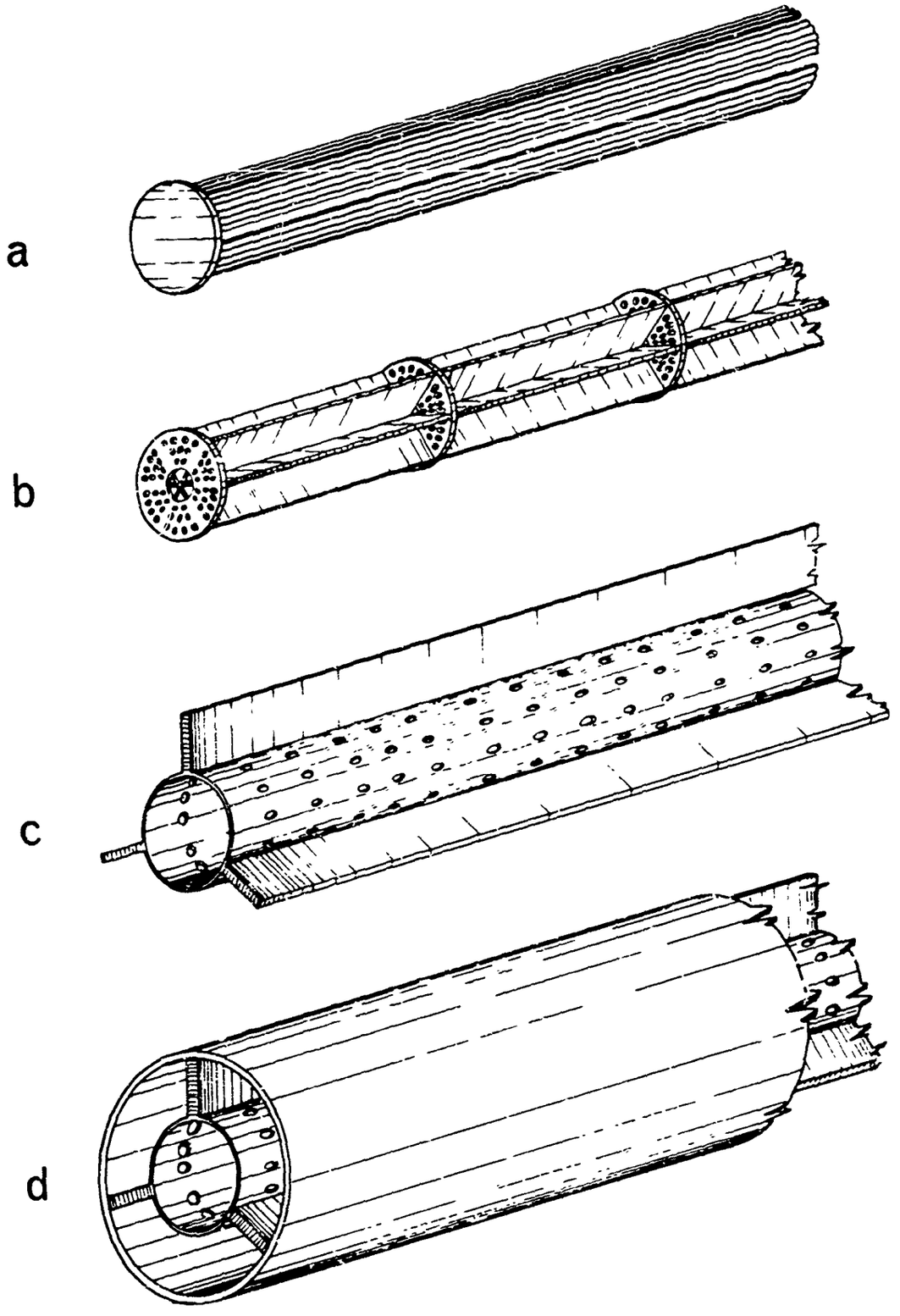


FIG. 1 CONSTRUCTION OF DIPOLE

a) Fifty–four 1.5 m, 6 mm diam. zinc rods attached to 10 cm diam. zinc plate
b) Plastic dividers to separate rods and reduce water flow
c) First surrounding tube
d) Second surrounding tube

possible, however, to increase the effective area of the electrode, without making it noticeably more difficult to handle, by increasing its length while holding the diameter constant. This of course requires a different baffle arrangement.

It was found experimentally that flow noise could only be effectively eliminated by using a baffle consisting of two concentric, perforated tubes surrounding the electrode material. With this arrangement only the outer layer of a spirally-wound electrode would be effective, the impedance of the water path precluding a significant contribution from the inner layers. It is important, however, as shown in Ref. 1, that the physical area of the electrode in contact with the water be considerably greater than the effective area, otherwise the polarization introduces a frequency-dependent impedance.

The increased surface area can be obtained in several ways, for example by using a corrugated construction, stacked disks, or parallel rods. For ease of construction and reproduction, the rod construction was selected. Measurements on the final dipole showed that the impedance was independent of frequency between 1 and 100 Hz.

The electrode construction is shown in Fig. 1. It consists of fifty-four 6-mm zinc rods 1.5 metres long soldered to a 10 cm diam zinc end plate. The rods are held in position by plastic dividers (Fig. 1b) that also serve as bulkheads to reduce water flow. To avoid bimetallic contacts in the water, the soldered points were

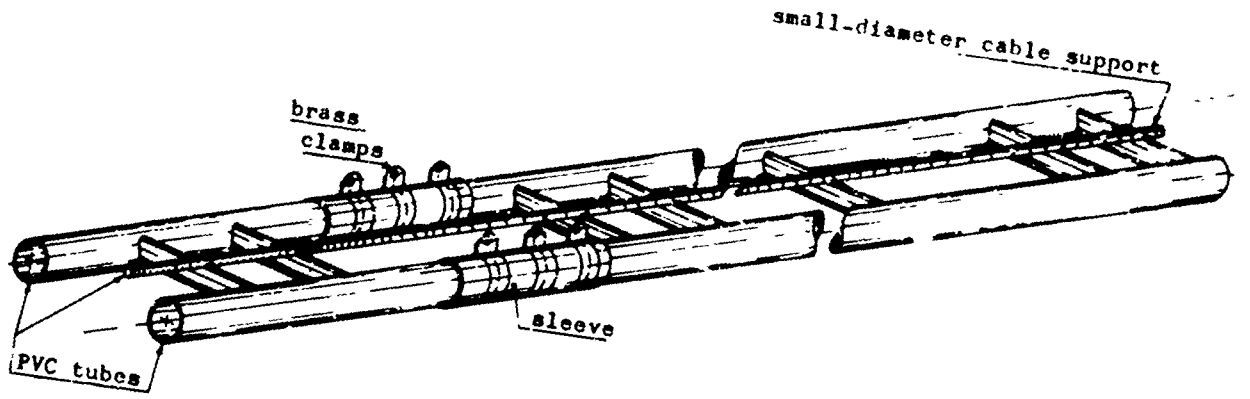


FIG. 2 CONSTRUCTION OF THE 7-m LONG DIPOLE FRAME

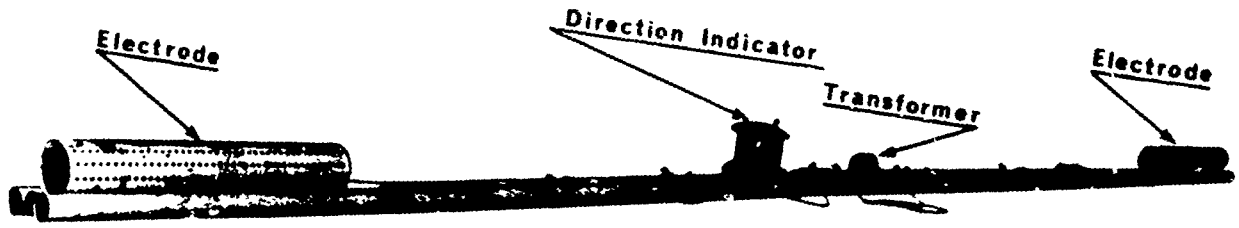


FIG. 3 COMPLETE DIPOLE ASSEMBLY

covered with araldite. The rod assembly was mounted in a double, perforated plastic tube container which served effectively to reduce the water motion to a negligible level.

The electrode may be approximated by a prolate ellipsoid with major and minor axes of $a = 75$ cm and $b = 4.2$ cm respectively. It was shown in Ref. 1 that the resistance of a dipole consisting of two such electrodes is given by:

$$R_s = \frac{\operatorname{arctanh}\sqrt{1-\left(\frac{b}{a}\right)^2}}{2\pi\sigma a\sqrt{1-\left(\frac{b}{a}\right)^2}} \quad *$$

Substituting a and b and taking the conductivity of sea water as $\sigma = 4$ mhos/m one obtains the value $R_s = 0.2$ ohms. The plastic protective tubes, however, increase the water path resistance so that in practice the resistance was found to be 0.6 ohms.

1.3 The Dipole Frame

The dipole frame, Fig. 2, consists of two parallel PVC tubes separated by spacers of the same material. For ease of handling and to make it easy to change the length, the frame is composed of 7-m sections. The electrodes are fixed to the frame with plastic screws. A completed dipole is shown in Fig. 3.

---

*In Ref. 1 this equation (Eq. 2.14) was incorrectly written with arctan instead of arctanh. The above equation is the correct one.

With this type of construction four dipole lengths are possible, of which the 14 m length has been used. These four lengths and their respective noise levels are listed in Table 1. The third column gives the theoretical noise level for an unprotected electrode system without taking flow noise into account. However, the equivalent noise voltage is increased by factors of 2.2 and 4.0 due to the perforated covering used to reduce flow noise and the preamplifier respectively. The calculated effective operational noise level is that listed in the fourth column.

TABLE 1

Physical length (m)	Electric length (m)	Minimum theoretical noise level (V/m $\sqrt{Hz}$)	Calculated noise level with protective covering and amplifier (V/m $\sqrt{Hz}$)
7	5	11.6×10^{-12}	10.4×10^{-11}
14	12	4.8×10^{-12}	4.3×10^{-11}
21	19	3.1×10^{-12}	2.8×10^{-11}
28	26	2.2×10^{-12}	2.0×10^{-11}

1.4 Transformer

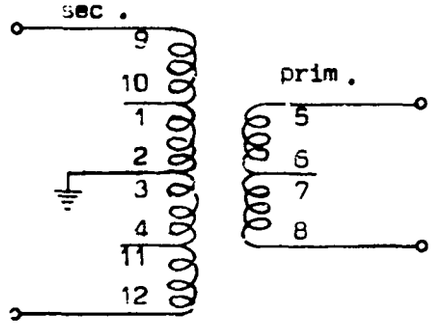
To match the low dipole impedance to the cable, a specially made transformer is attached to the dipole frame. The same method of

construction was used for this transformer as for that described in Ref. 1. The details of construction are as follows:

Tape wound core

Cross section 30 x 30 mm

Inner diameter 80 mm



1- 2 and 3- 4
5- 6 and 7- 8
9-10 and 11-12
are wound in parallel

Winding Scheme

	Wire (Strands x Diam)	Turns
1- 2	8 x 0.3 mm	175
3- 4	8 x 0.3 mm	175
5- 6	2 x 6 x 0.5 mm	34
7- 8	2 x 6 x 0.5 mm	34
9-10	8 x 0.3 mm	160
11-12	8 x 0.3 mm	160

To ensure matched characteristics the windings were wound in matched pairs, as shown. The transformer container is seen in the centre of the dipole in Fig. 3.

1.5 Cable

The characteristics of the cable used to transmit the signal from the dipoles to the amplifier onshore are:

i) 4 conductors: tinned copper 0.9 mm^2 (30 x 0.2 mm strands)

ii) dc resistance: 20 Ω/km

iii) Capacity between pairs of wire: 110 pF/m

iv) Screen: steel braid, wire 0.30 mm

v) External picket: 1 mm, polychloroprene

vi) Average outer diameter: 11 mm

vii) Mechanical strength in excess of 600 kg

In practice the two conductors are connected together to form a single shielded pair. Marsh and Marine watertight connectors are used throughout.

1.6 Amplifier

A completely new amplifier was designed and constructed to overcome some of the problems associated with the one described in Ref. 1. The circuits are shown in Figs. 4 & 5. The pre-amplifier is a low noise, balanced dc amplifier with heavy feedback from the output to the first transistor. The input impedance is 50 kΩ and the gain 83 dB. The low frequency and 50 Hz interferences are

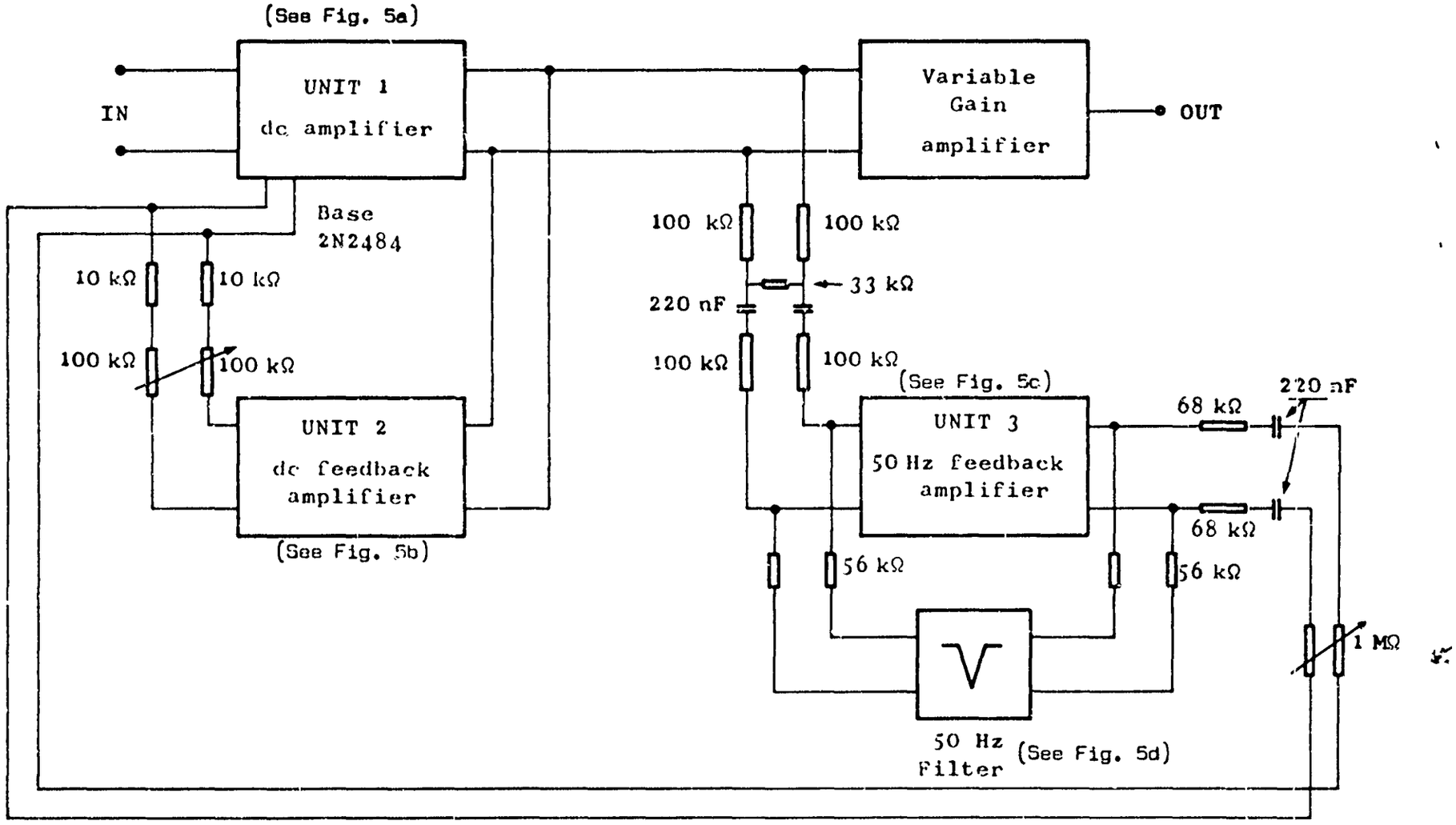
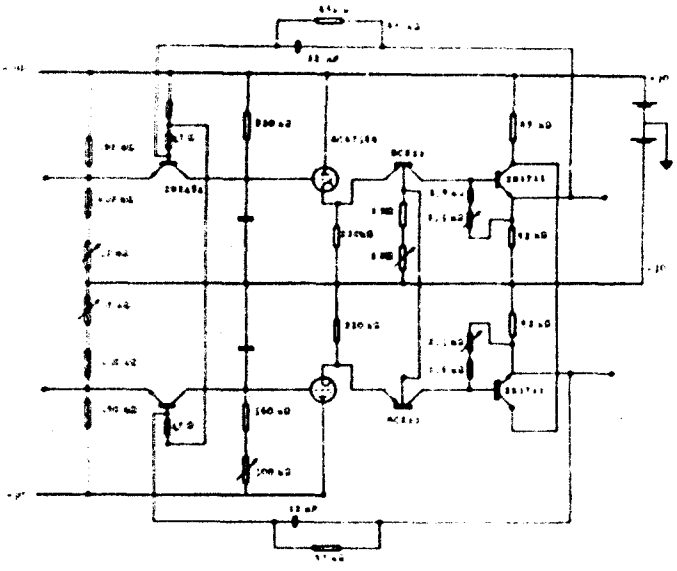
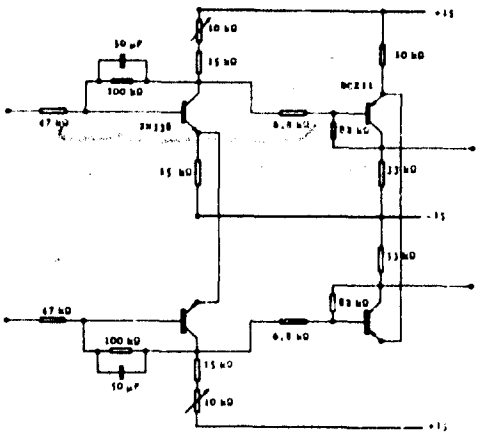


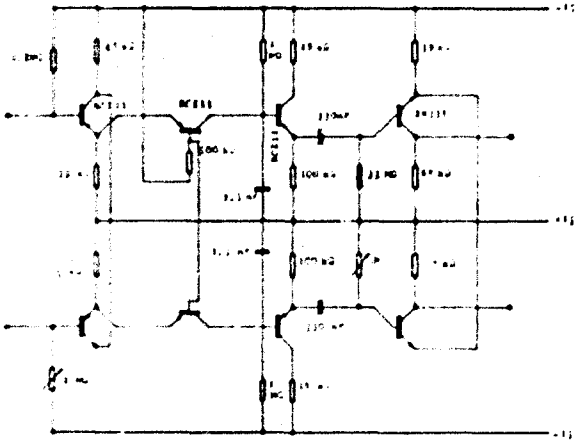
FIG. 4 AMPLIFIER CIRCUIT



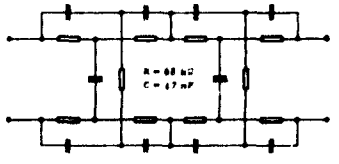
(a) dc amplifier



(b) dc feedback amplifier



(c) 50 Hz feedback amplifier



(d) 50 Hz filter

FIG. 5 CIRCUITS OF UNIT BLOCKS SHOWN IN FIG. 4

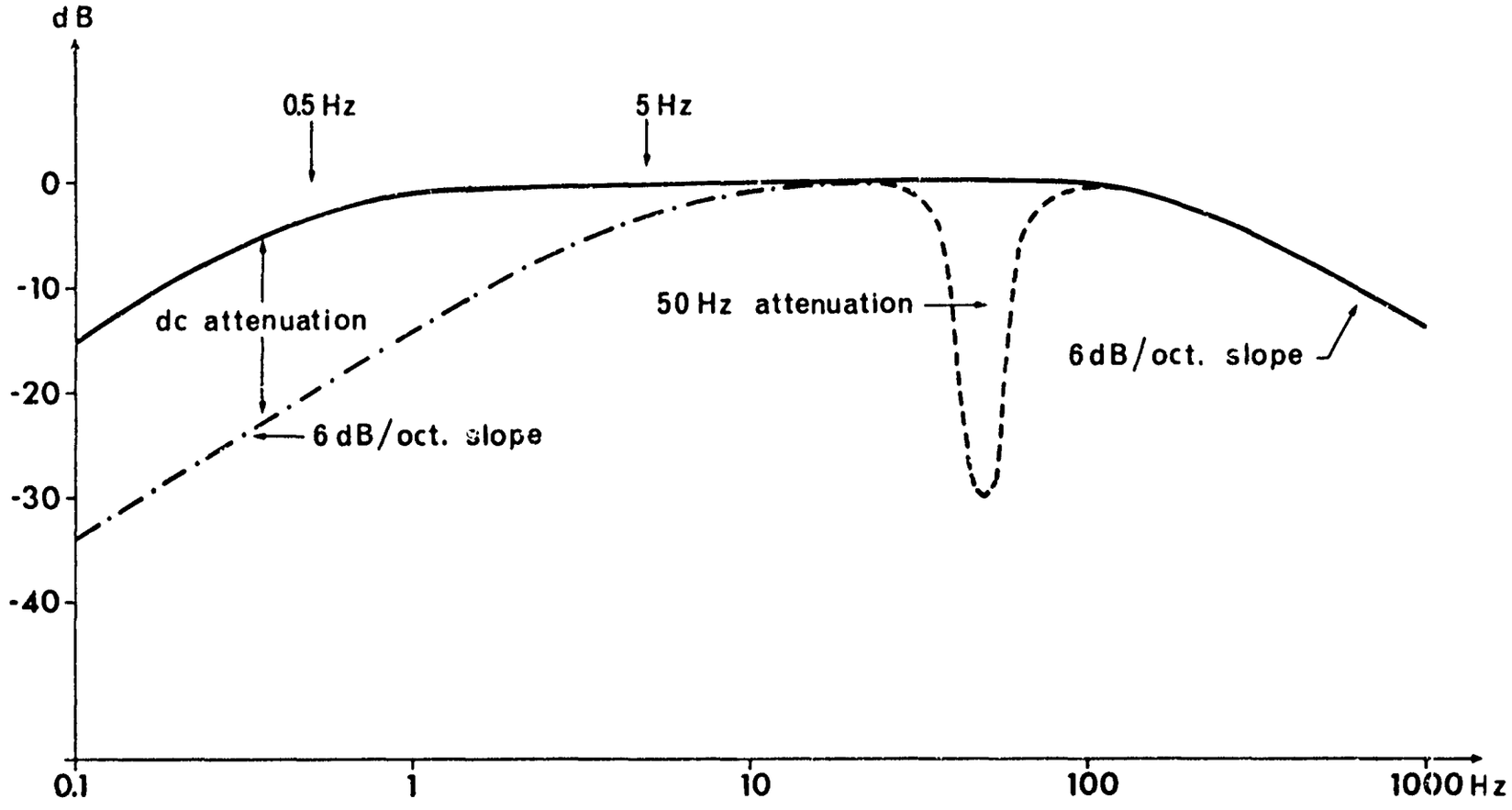


FIG. 6 AMPLITUDE CHARACTERISTICS OF AMPLIFIER WHEN dc AND 50 Hz FEEDBACK ARE AT THEIR EXTREMES

attenuated by separate variable-gain feedback loops. This provides a 6 dB/oct low-frequency roll-off variable from 0.5 to 5 Hz, and a narrow-band 50 Hz rejection from 0 to 30 dB. The frequency response is shown on Fig. 6. The noise of the preamplifier with 100 Ω as generator impedance is given by a noise factor F rarging from 12 dB at 1 Hz to 8 dB at 25 Hz.

1.7 Direction Indicator

The direction indicator, which is fixed to the centre of the dipole frame, consists of a vertically-suspended vibrating coil (Fig. 7).

The magnetic flux through the coil is given by

$$\varphi = AH \cos(\theta_o + \theta),$$

where

A = area of coil,

H = horizontal magnetic field strength,

θ_o = average direction of the axis of the coil relative to magnetic north,

θ = deflection of coil from θ_o.

The voltage generated in a coil of n turns is, then, using rationalized MKS units,

$$V = n \frac{d\varphi}{dt} = n AH \sin(\theta_o + \theta) \frac{d\theta}{dt} \text{ Volts}$$

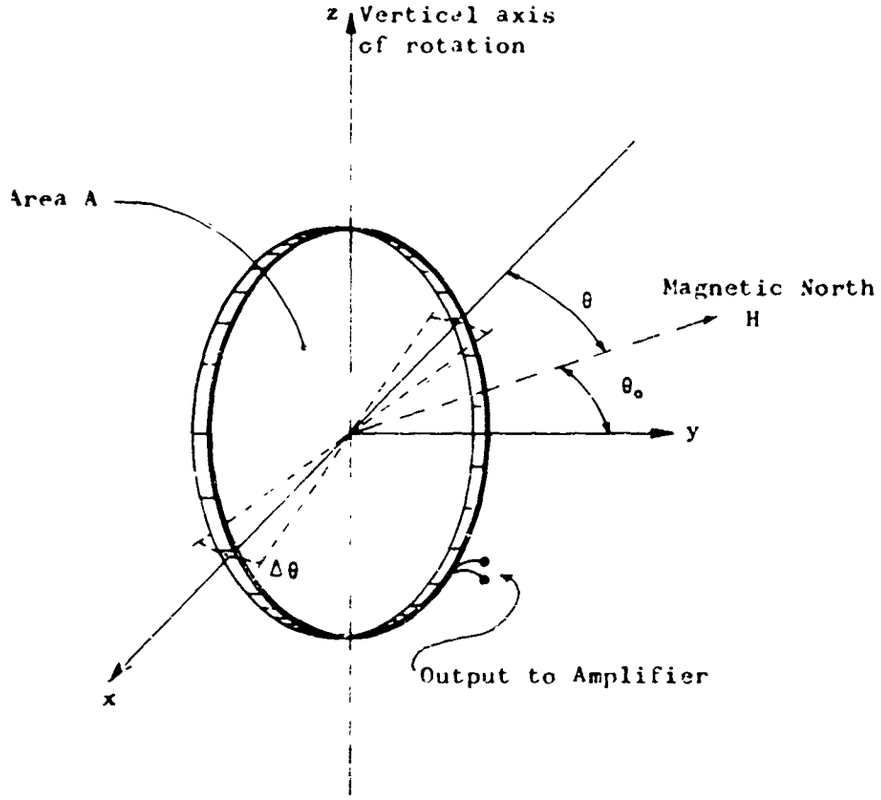


FIG. 7 SCHEMATIC DIAGRAM OF DIRECTION INDICATOR

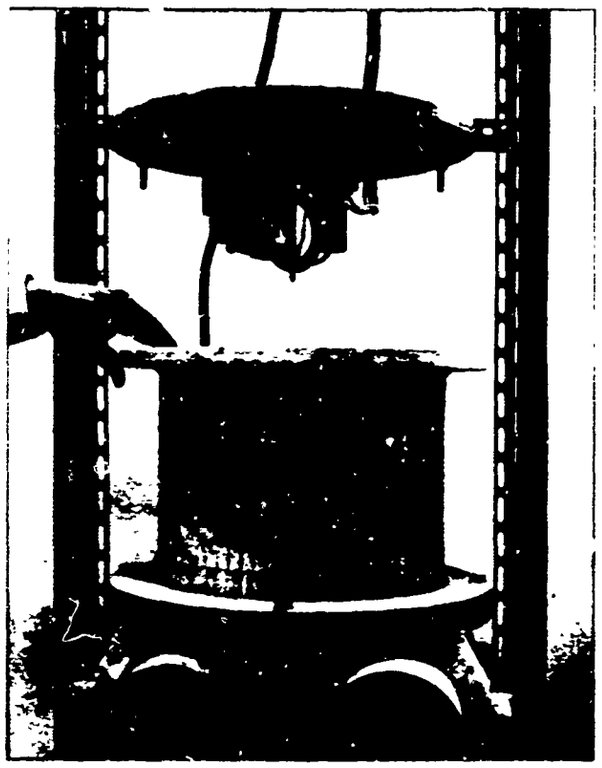


FIG. 8 DIRECTION INDICATOR

For low amplitude simple harmonic motion we may take

$$\theta = \eta \cos \omega t,$$

giving

$$V = \eta \, AH \, \Delta\theta \, \eta\omega \sin \omega t \sin(\theta_o + \eta \cos \omega t) \, .$$

This is a complex function whose amplitude and harmonic content depend on the average direction, θ_o, from magnetic north.

We can obtain the first few harmonics by expanding

$$V(x) = V_o \eta \sin x \sin(\theta_o + \eta \cos x)$$

in a Fourier series, where V_o is a constant, and $x = \omega t$.

The coefficients of the k^{th} harmonic are given by

$$a_k = \frac{1}{\pi} \int_o^{2\pi} V(x) \cos kx \, dx \, ,$$

and

$$b_k = \frac{1}{\pi} \int_o^{2\pi} V(x) \sin kx \, dx \, .$$

Since $V(x)$ is an odd function,

$$a_k \equiv 0 \, .$$

b_k can readily be found using the relations

$$\int_{-\pi}^{\pi} \sin(\eta \cos x) \cos n\, x\, dx = 2\pi \sin\frac{n\pi}{2}\, J_n(\eta)$$

and

$$\int_{-\pi}^{\pi} \cos(\eta \cos x) \cos n\, x = 2\pi \cos\frac{n\pi}{2}\, J_n(\eta).$$

After simplification we obtain

$$b_k = (-1)^{\frac{k-1}{2}}\, n\, AH\, \omega 2k \sin\theta_o\, J_k(\eta) : \quad k \text{ odd},$$

$$-(-1)^{\frac{k}{2}}\, n\, AH\, \omega 2k \cos\theta_o\, J_k(\eta) : \quad k \text{ even},$$

where $J_k(\eta)$ is a Bessel function of the first kind.

For small amplitude vibration the Bessel function may be approximated by

$$J_k(\eta) = \frac{\eta^k}{k!\ 2^k}$$

and we obtain, keeping the first two harmonics,

$$V = n\, AH\, \omega\eta(\sin\theta_o\, \omega t + \frac{\eta}{4} \cos\theta_o \sin 2\, \omega t).$$

First, it should be noted that since $\eta << 1$ the fundamental component, ω, is the largest, except as θ_o approaches zero. The null when the axis of the coil is in the magnetic north-south direction can be used to align the device.

As constructed, the direction indicator consists of a 3125-turn coil of area 7×10^{-3} m^2 suspended from the top of the watertight container by a universal joint (Fig. 8). The coil is given a three-degree amplitude, 7.2 Hz vibration by means of a dc motor-driven eccentric disk. The motor is shielded by an iron container. The motor current and iron container introduce an error in the field direction, but it has been found that for practical purposes the error is the same in each of the units constructed, so that the alignment of the electrodes can be accurately established by this detector.

Using a horizontal field strength of 2.25×10^{-5} Wb/m^2 one obtains

$$V = 832(\sin \theta_o \sin \omega t + .052 \cos \theta_o \sin 2 \omega t) \mu V .$$

An error of 1° in alignment thus produces a 29 μV peak-to-peak signal. A simple narrow-band amplifier and rectifier serves as a null-detector.

2. EXPERIMENTAL RESULTS

Measurements were made with a pair of dipoles near the Island of Tino. (Fig. 9).

Two dipoles were assembled on the shore and towed suspended 1 metre below the surface to the desired location. A system of ropes was then used to slowly lower the dipole while the direction was monitored onboard the launch ship. Orientation to an accuracy of 2° was found to be practical.

One of the cables was caught in a ship's anchor shortly after laying, and its cable was damaged beyond repair. Thus only a short length of cable was available for one of the dipoles, which had to be placed in much shallower water than originally planned.

The recording system was that shown in Fig. 10. A typical recording of the background signal received on the two dipoles and of the difference signal is shown in Fig. 11. The corresponding power spectra obtained with the ISAC Statistical Analyser are presented in Fig. 12. Since the Schumann resonances at 8, 14, 20 Hz are not evident in the spectrum of the difference signal, the cancellation of locally-generated industrial noise — still well above instrumentation noise — was not optimum. It is possible, though

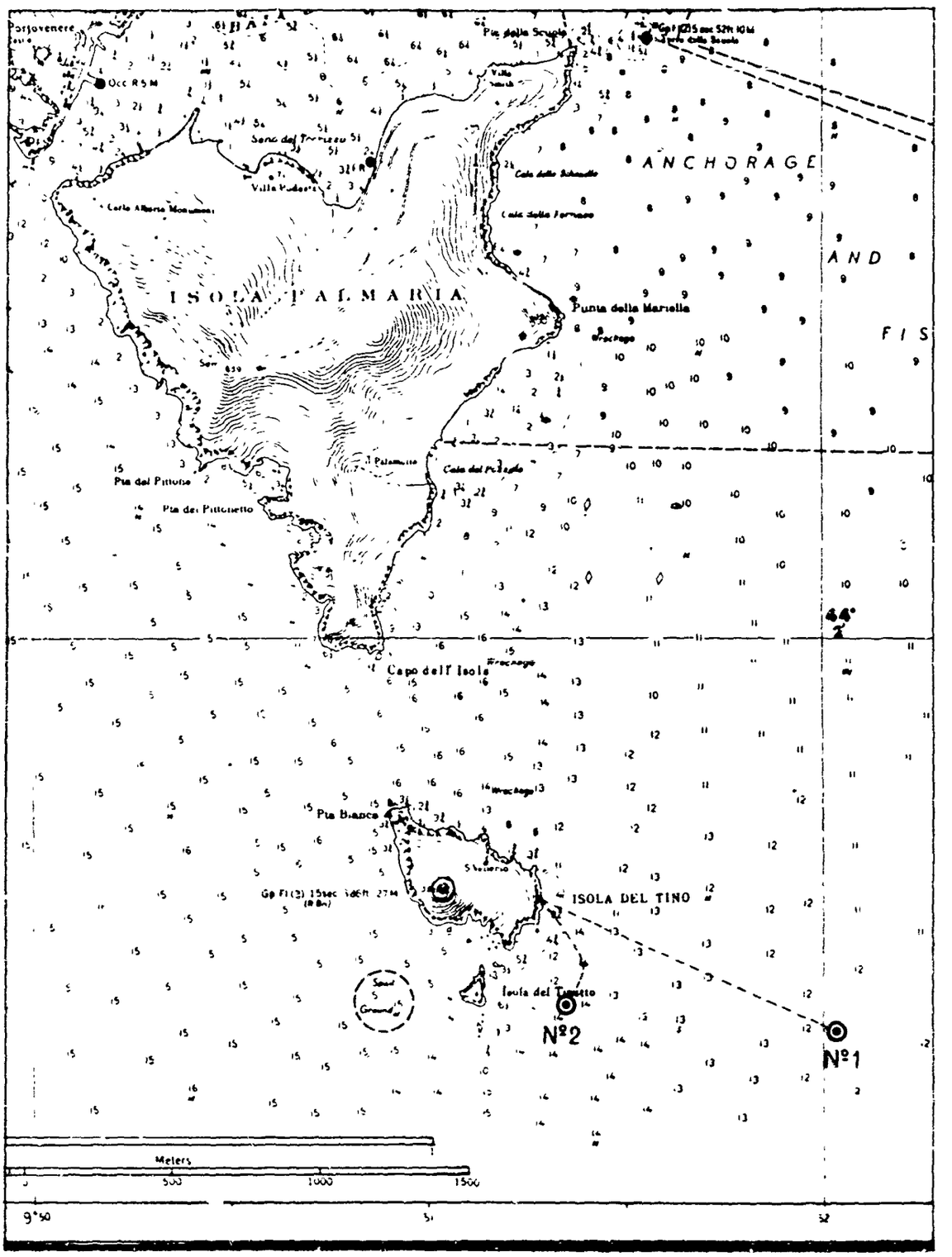


FIG. 9 POSITIONS OF DIPOLES IN THE GULF OF LA SPEZIA

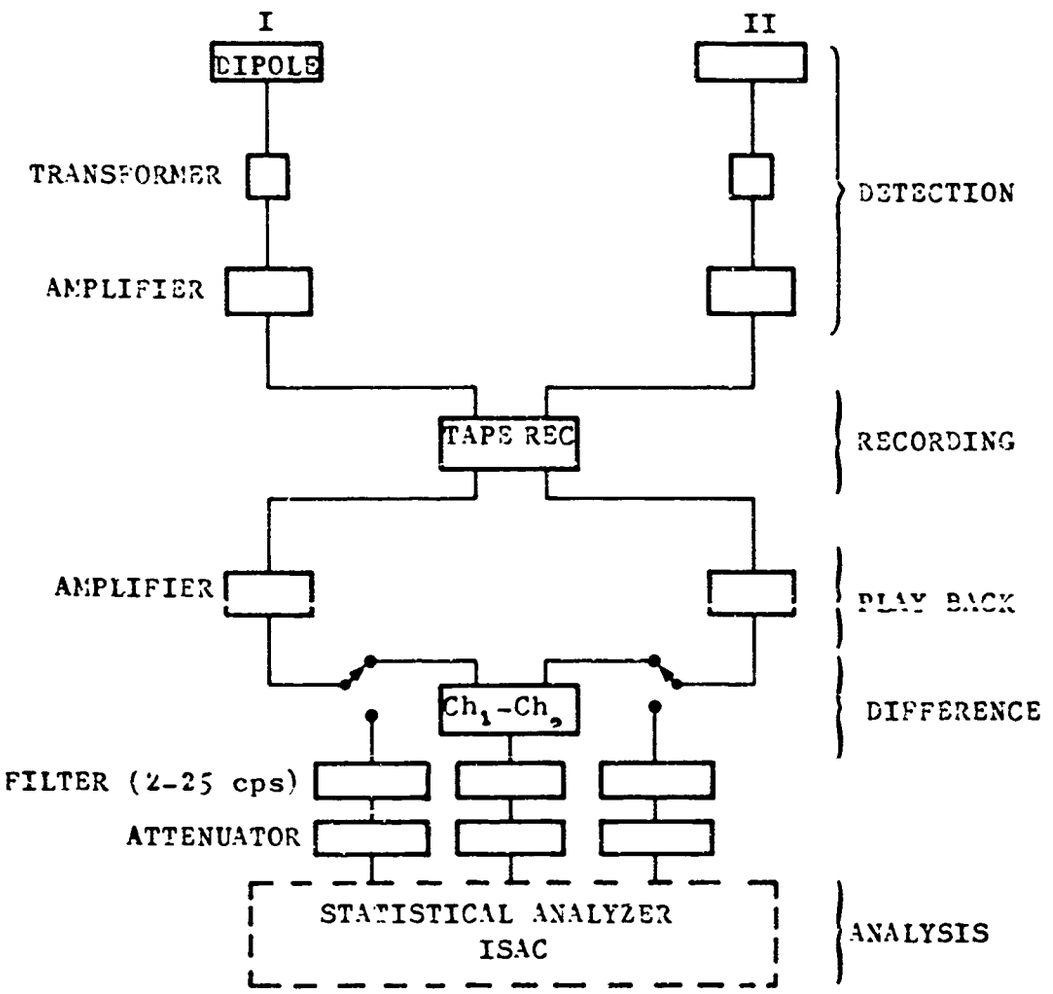


FIG. 10 GENERAL BLOCK DIAGRAM

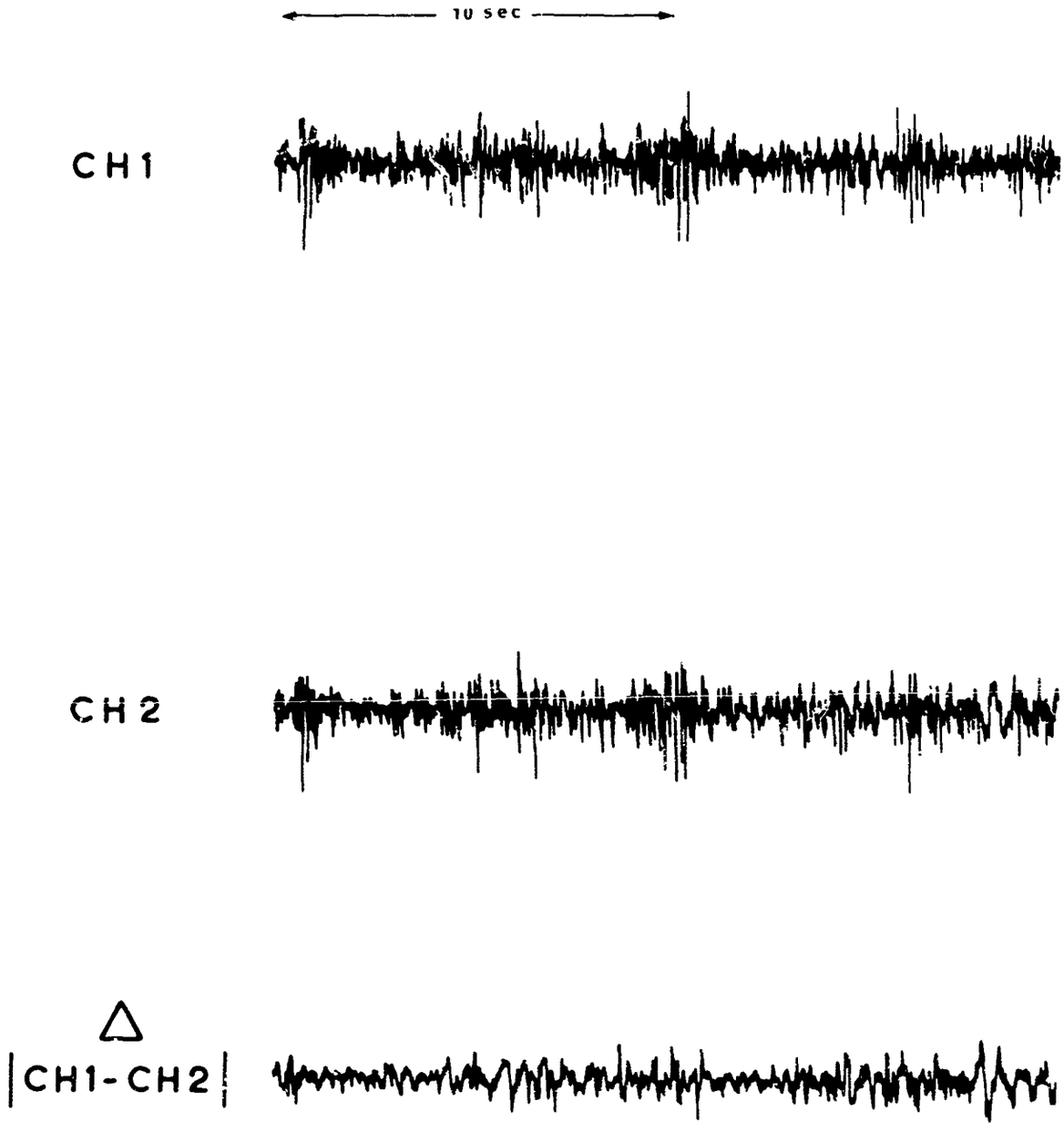


FIG. 11 TYPICAL RECORDING OF THE BACKGROUND SIGNAL RECEIVED BY TWO DIPOLES 1 km APART AND OF THE DIFFERENCE SIGNAL

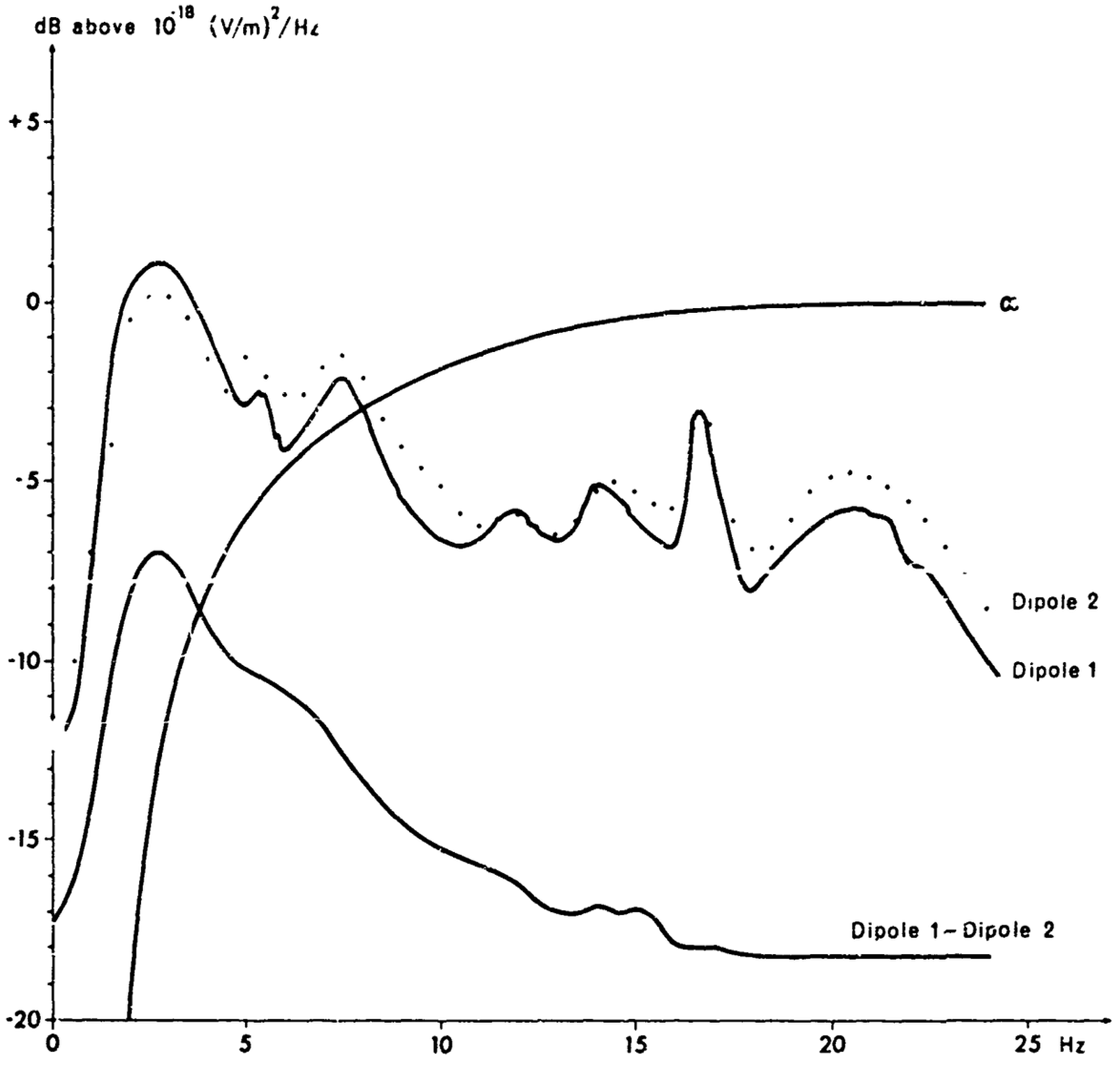


FIG. 12 POWER SPECTRA OF NATURAL BACKGROUND NOISE MEASURED BY TWO DIPOLES 1 km APART AND OF THE DIFFERENCE SIGNAL
(The power spectra are multiplied by the factor α)

unlikely, that microseismic activity was a contributing noise source. It is believed that recording the difference signal, rather than deriving it from the playback would improve the cancellation. Also, the direction and magnitude of the electric field is affected by geological parameters such as distance from the coast line, the water depth, and bottom impedance. Due to the short cable available these were not optimized for the recording shown here.

CONCLUSION

Reference 1 describes an electrical dipole supported by a passive platform at the sea surface, while the present paper describes the equipment used to measure the bottom field strengths in the sea. It would have been interesting to investigate the possibility of having an electric dipole supported by a moving platform, but this problem will not be taken up. The sensitivity obtained (5×10^{-11} V/m $/\sqrt{\text{Hz}}$ for the 14-m dipole) could be improved by increasing the dipole length, and by the use of a better low-noise amplifier. The electric dipole mentioned is not restricted to measurements in the frequency interval 1-32 Hz. However, outside this range new problems develop. With slow-varying dc signals the polarization noise of zinc electrodes is too dominant; in this case non-polarized Silver-Silver Chloride electrodes are believed to be more useful. At high frequencies, the dipole impedance is complex and the current density is non-uniform along the dipole.

REFERENCES

1. T. Strarup, "Equipment for Measuring the Horizontal Electric Field-strength at Sea in the Frequency Interval of 1-32 cps", SACLANTCEN Technical Memorandum No. 96, January 1966, NATO UNCLASSIFIED.